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Vonder, Marleen

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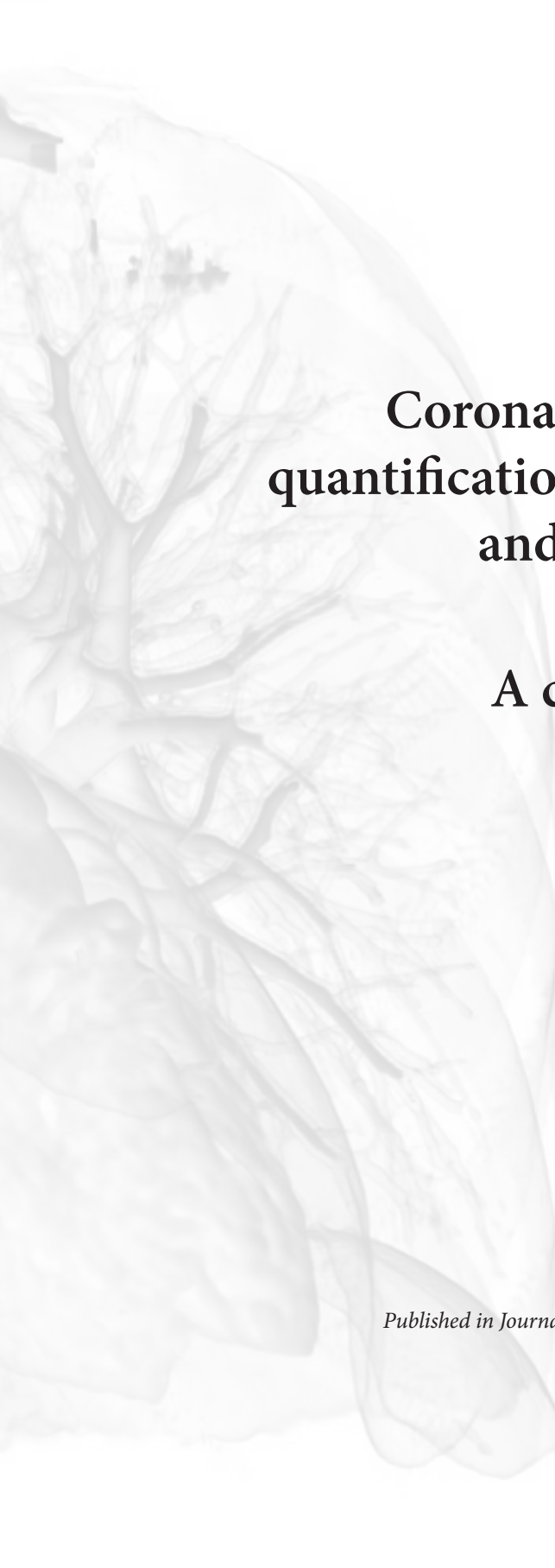
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Coronary artery calcium quantification on first, second and third generation dual-source CT: A comparison study

Marleen Vonder

Gert Jan Pelgrim

Sèvrin E.M. Huijsse

Holger Haubenreisser

Mathias Meyer

Peter M.A. van Ooijen

Matthijs Oudkerk

Thomas Henzler

Rozemarijn Vliegenthart

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Abstract

Background

Differences in coronary artery calcium (CAC) quantification of successive CT systems of one vendor could impact results of CAC screening and progression studies. The purpose of this study is to compare CAC quantification between three generations of dual-source computed tomography (DSCT) systems.

Methods

Three DSCT generations were used to repeatedly scan an anthropomorphic chest phantom and three inserts. The first and second insert contained 100 small and nine large calcifications, respectively, to determine detectability, and the Agatston and (calibrated) mass score, respectively. A third insert containing a moving artificial coronary artery was used to determine impact of movement on calcium scoring. Data were acquired at 120 kVp, 90 reference mAs with prospective electrocardiographic(ECG)-gating at sequential and high-pitch spiral mode, for respectively first and second/third generation DSCT. Differences and variability in detectability and calcium scores were analyzed.

Results

Although noise levels differed ($p < 0.002$), no differences in detectability were found between the three DSCT generations; median (range) for first, second and third generation were 11(8), 11(4) and 12(2) out of 100 calcifications ($p > 0.272$). Between second and third generation no difference was found in Agatston score for the large calcification phantom ($p > 0.05$). The intra-scanner variability and inter-scanner median relative difference ranged for Agatston score from 2.1-8.3% and 0.5-12.7% and for mass score from 1.4%-4.4% and 0.7-5.6%. Overall, intra-scanner variability was lowest for third generation DSCT.

Conclusion

The three DSCT generations have similar detectability of calcifications. Median Agatston and mass score differed by no more than 12.7% and 5.6%.

Introduction

Coronary artery calcium (CAC) scoring by computed tomography (CT) is primarily used as a cardiovascular disease (CVD) risk stratification tool in asymptomatic individuals. Further risk stratification can be performed by analyzing CAC progression. Progression of $\geq 15\%$ compared to baseline is associated with an increased CVD risk, whereas in patients with stable CAC the risk is the same across risk categories [1]. Detection of CAC progression by use of the Agatston score can be difficult, because significant differences in Agatston scores can be present between CT systems [2–4]. Other CAC scoring parameters like the mass score have shown lower inter-system variability than the Agatston score [2]. In large multi-center screening trials and in follow-up studies, it is often not possible to use exactly the same type of CT system. Possibly, differences in CAC scores also play a role in consecutive scanner generations of one vendor. Nevertheless, little is known about the impact of differences between successive CT systems of one vendor (e.g. differences in generation power, detector type and collimation) on CAC scoring. The purpose of this study was to compare coronary calcium quantification of three consecutive generations of dual-source CT systems (DSCT) of one vendor.

Materials and methods

An anthropomorphic chest phantom and additional fat rings were used to simulate small, medium and large chest size (Thorax, extension ring M and L, QRM, Möhrendorf, Germany) (*Figure 1*). The thorax contained an opening at the level of the heart in which two static (insert 1: small calcifications, insert 2: large calcifications) and one dynamic (insert 3: moving artificial calcium artery) insert were placed consecutively. See *Table 1* for the details of each insert, containing calcifications corresponding in size, density and speed to those found in vivo [5–7]. All three chest-sizes were scanned with inserts 1 and 2, and the medium chest size was used with insert 3 for all speeds.

The phantom was scanned five times for insert 1 and 2, and three times for insert 3 on first, second and third generation DSCT (SOMATOM Definition; Definition Flash; Force; Siemens Healthcare, Forchheim, Germany). See *Table 2* for acquisition and reconstruction details per generation, as recommended by the vendor. High-pitch spiral scan mode was used for second and third generation DSCT, whereas for first generation a sequential scan mode was recommended by the vendor.

The number of calcifications on images of insert 1, detected with semi-automatic CAC software (Aquarius iNtuition Viewer, Version 4.1.11, TeraRecon Inc, Foster City, USA)

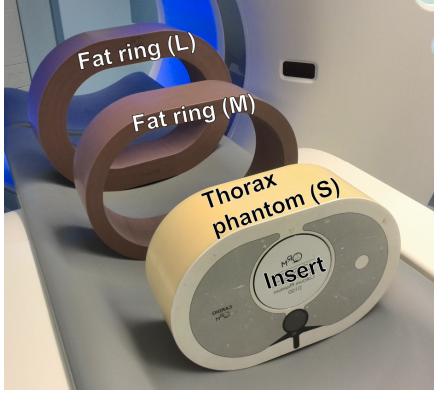


Figure 1 – An anthropomorphic chest phantom and fat rings were used to simulate patients with a small, medium and large chest size. The phantom contained an opening at the level of the heart in which consecutively static and moving calcium inserts were placed.

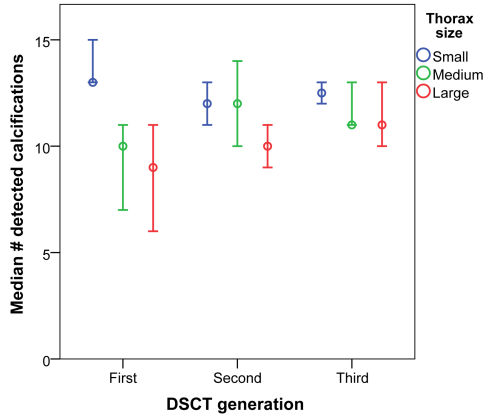


Figure 2 – Detectability of calcifications. The median detected number of calcifications (out of 100) that were detected and the 95% confidence interval, based on small calcification insert.

was defined as the calcium detectability to determine the impact of DSCT generations on zero score. Agatston and mass score were quantified for insert 2 and 3. Mass-calibration factors were determined for each scan based on calibration planes in the inserts [2]. Image quality was quantified by determining the noise level.

Statistical analysis

Data are presented as median and interquartile range (IQR) for detectability, Agatston and mass score. The variability of the Agatston score and mass score was calculated as follows:

$$\begin{aligned} \text{Variability} &= (\text{MADM} \cdot 100\%) / \text{median} \\ &= (\text{median} (|x_i - \text{median}(x)|) \cdot 100\%) / \text{median} \end{aligned} \quad (1)$$

With *MADM* representing the median absolute deviation from the median (*MADM*) and *x* the calcium score. Mann-Whitney U testing was used to compare the measurements of the different DSCT generations per chest size, and Kendall's tau-b (τ_b) was used to determine trends in calcium scores. To express the magnitude of any

score differences between generations of DSCT (G_1, G_2, G_3), a median relative difference (MRD) was calculated as follows:

$$MRD = (|median\ score\ G_1 - median\ score\ G_2| \cdot 100\%) / (median\ score\ G_1 + median\ score\ G_2) / 2 \quad (2)$$

Results

Image quality and radiation dose are listed in *Table 3*. No significant difference in the number of detected calcifications was found between any of the DSCT generations ($p > 0.272$) based on insert 1 (*Figure 2*). However, detectability decreased for increasing patient size ($\tau_b = -0.543$, $p < 0.01$) for all DSCT generations.

Total Agatston and mass scores of insert 2 and 3 are depicted in *Figure 3*. Agatston and mass score variability for first, second and third generation was respectively 5.2% and 4.4%, 2.1% and 1.6%, 3.2% and 1.4%. Taken all patient sizes together, similar Agatston scores were found for second and third generation ($p = 0.653$), and similar mass scores for first and second ($p = 0.653$). Lower Agatston score was found for first compared to second ($p = 0.019$) and third generation ($p = 0.026$), and lower mass score was found for third generation compared to first ($p < 0.01$) and second ($p < 0.01$). The median relative difference between first and second generation was 5.6% and 0.5%, between first and third was 6.1% and 5.1%, between second and third was 0.5% and 4.6%, for respectively Agatston and mass. The Agatston score decreased with increasing patient size ($\tau_b = -0.525$, $p < 0.01$), whereas the mass score did not ($\tau_b = -0.013$, $p = 0.909$), with the same trend for all DSCT generations.

No difference in Agatston ($p > 0.177$) and mass ($p > 0.05$) score were found between the DSCT generations for insert 3, with coronary artery speed of 0 mm/s. At speed 10-30 mm/s, second generation showed significantly lower total Agatston score compared to first ($p = 0.021$) and third ($p = 0.008$) generation. The median relative difference at speed 0 mm/s between first and second generation was 2.8% and 3.5%, between first and third 3.3% and 5.6%, and between second and third 6.1% and 2.3%, for respectively Agatston and mass score.

The Agatston ($\tau_b = -0.452$, $p < 0.01$) and mass ($\tau_b = -0.628$, $p < 0.01$) score decreased for increasing speed of the coronary artery (insert 3) for all generations. The variability of respectively the Agatston and mass score for the moving coronary artery was for

Table 1 – Calcium insert details

	Insert 1 (D100)	Insert 2 (CCI)	Insert 3 (Sim2D)
Type	Static	Static	Moving
Speed (mm/s)	0	0	0, 10, 20, 30
Calcifications			
Number	100	9	3
Size (mm ³)	0.1-6.3	0.8, 21.2, 98.2	9.1, 24.6, 62.8
Density (HA/cm ³)	90-540	200, 400, 800	401

Table 2 – Vendor recommended protocols

	First	DSCT generation	
		Second	Third
Scan mode	Sequential	High-pitch spiral	High-pitch spiral
Collimation	2×64×0.6	2×128×0.6	2×192×0.6
Scan speed (mm/s)	-	458	737
Temporal resolution (ms)	83	75	66
Tube voltage (kVp)	120	120	120
Tube current (ref mAs)	90	90	90
Reconstruction matrix	512×512	512×512	512×512
Field of View (mm)	250×250	250×250	250×250
Kernel	B35f	B35f	Qr36d
Slice thickness / increment (mm)	3.0 / 3.0	3.0 / 1.5	3.0 / 1.5

Table 3 – Image quality and radiation dose

	First	DSCT generation		p-value
		Second	Third	
Median (IQR) image noise (HU)	15.6 (13.7-18.0)	20.3 (18.8-21.7)	17.3 (16.2-19.8)	<0.002*
Median (range) effective tube current (eff mAs)	206 (30-322)	66 (28-121)	85 (40-145)	0.011† 0.217
Median (range) CTDI _{vol} (mGy)	7.1 (1.1-11.1)	1.1 (0.5-2.0)	1.5 (0.7-2.4)	-

* Image noise was higher for 2nd compared to 1st and 3rd generation DSCT

† Tube current was higher for 1st compared to 2nd, and comparable for 2nd and 3rd

first generation 5.3% and 3.4%, for second generation 8.3% and 4.1%, and for third generation 3.4% and 4.4%. The median relative difference at coronary artery speeds 10-30 mm/s between first and second was 12.7% and 2.8%, between first and third 1.3% and 2.1%, between second and third 11.4% and 0.7%, for respectively Agatston and mass. No significant differences in mass score was found for coronary artery speed 0 mm/s ($p=0.875$) and 10-30 mm/s ($p=0.322$) between any of the three DSCT generations.

Discussion

Similar detectability of coronary calcifications and small variations in median Agatston score, ranging from 0.5-6.1%, were found across the three DSCT generations for the static insert, to a maximum of 12.7% for the dynamic insert. Contrary, the mass score varied only by 0.5% to a maximum of 5.1%, with no significant differences between the generations for the dynamic insert. Likewise, the variability in mass score tended to be lower than in Agatston score for all generations DSCT, with lowest Agatston variability for third generation DSCT.

Although the zero score is an important determinant in CAC risk stratification [8], very few previous studies have investigated the impact of CT-system on the zero score. A study by Groen et al. [9] showed highest detectability for electron-beam CT (22:100) compared to multi-detector CT (17:100), while in our study the highest detectability of any of the DSCT generations was 15:100.

In our study we found comparable Agatston and mass scores and magnitude of relative difference between DSCT generations compared to the relative difference in scores between different types of MDCT studied by McCollough et al. [2], based on insert 2. In studies by Willemink et al. and Ghadri et al. CAC quantification was compared between CT systems of different vendors, of which we derived a median relative difference in Agatston score of respectively 6.4-43.9% [3] and 0.7% [4]. This shows that relative difference between scanners can be highly variable, and that small relative differences between scanners are not exclusive for CT systems of the same vendor.

Studies have reported intra-scanner variability of 12-20% and 1.5-13.7% for respectively Agatston and mass score [10-14]. Although the results of our study show lower to comparable results for intra-scanner variability, direct comparison is difficult because CAC levels were different for these studies and measurement error increases with increasing CAC levels [10].

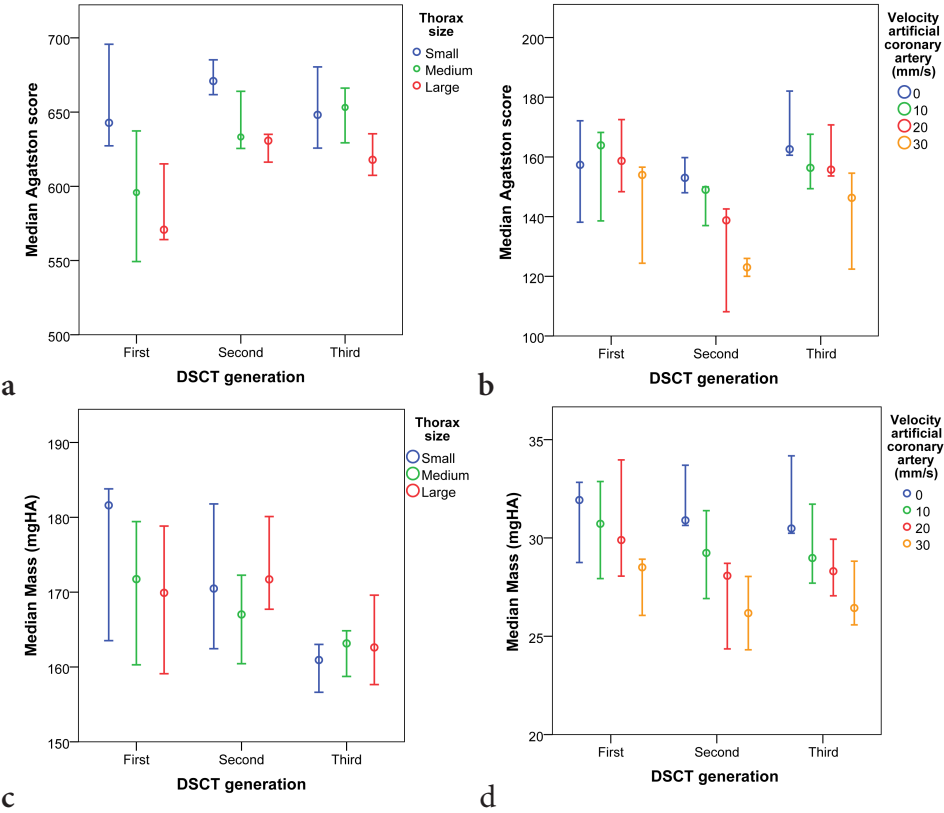


Figure 3 – Agatston and mass score. The median and 95%-confidence interval of the Agatston and mass score (a/c) per patient size, based on insert 2; and (b/d) per velocity of insert 3; for the three DSCT generations.

Limitations

In this study, similar quality reference tube currents were used, but image noise differed significantly for second generation compared to first and third. Nonetheless, this did not affect the detectability and Agatston score, and former studies showed that tube current has negligible impact on calcium scoring [15]. The three generations probably used different dose modulation curves to determine a suitable effective tube current for each patient chest size. Although this should lead to equivalent noise levels across patient sizes within one generation, this could have caused the differences between DSCT generations.

For the moving insert, the Agatston score was lower for second generation DSCT compared to first and third. Hypothetically, the second generation's scan lower maximum high-pitch scan speed may have caused partial volume effects which led to lower maximum HU values of the calcifications, resulting in a lower Agatston score. This effect was not found for mass score, since this score does not depend on maximum HU values.

To conclude, the three DSCT generations had similar detectability of calcifications. Median Agatston and mass score differed by no more than 12.7% and 5.6%. This indicates that CAC progression can only be concluded if the Agatston and mass score increase above this level compared to baseline.

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Part III

General discussion & summary

